III.—*On the Lower Portion of the River Indus.* By Colonel C. W. Tremenheere, c.b., Royal Engineers, f.r.g.s.

Read, December 10, 1866.

The portion of the Indus to which the following remarks apply is comprised within the province of Sind, from its most northern boundary at Mittee, on the Punjaub frontier, to the sea. The direct distance between these points is 330 miles, but by the windings of the river, as measured on the large map of the Revenue Survey, the distance is about 540 miles.

From the extensive series of levels which have been carried out by Government for irrigational purposes, many of which having been reduced to the same datum, viz., the mean sea-level as fixed by the officers of the Great Trigonometrical Survey, Mittee is 227·22 feet above the datum line; and as this point is very slightly above the water-level during the inundation of the river, the surface slope of the river may be stated to be nearly ·478 feet or 5·7 inches per mile. If the slope be calculated from Mittee to the bench-mark nearest to the river mouth, the result gives 5·8 inches per mile, or nearly identical with the former. The slope calculated from the direct distance gives ·78 feet or 9·3 inches per mile.

The general course of the river between Mittee and Sukkur is in a south-westerly direction; but immediately after passing the latter place it turns to the northward and westward, and from thence to near Oonurpoor describes a large curve having a radius of about 80 miles, with a versed sine of 60 miles. From Oonurpoor to the sea it does not diverge much from a direct course, although there are considerable bends.

I have endeavoured to mark approximately the limits of the valley of the Indus by shading the high ground which bounds it. This limit is absolute along the whole of the western side of the valley, and is marked by the hilly district, extending from Cape Monze to the west of Kurrachee, in a wide curve by Kotree and Sekwan to the entrance to the valley of Shahpoor. This hill range, portions of which are upwards of 6000 feet high, extends without a break to the Bolau Pass, and is connected with the great Sooliman Range. On the eastern side, on the contrary, the valley of the Indus may be said to have no very defined boundary; with the exception of the range of limestone hills, extending from Sukkur and Rosee to Kote Dejee, which terminates to the south in low sand-hills (similar in every respect to the desert tract which extends along the whole of this side of the valley) there is no high land which defines the boundary of the Indus Valley to the eastward.

Map of the
DELTA OF THE INDUS
to accompany the Paper by
Col. C. W. Tremenheere, C.B. R.E.

68
25
24
HYDRABAD
KOTREE
JERRUCK
Kadajee R.
Thadajee R.
Dumlote R.
Sookhan R.
S
I
N
D
Railway
Meanee
Ghizree Bunder
Kadru
R. Charu
R. Jhiri
Gharrah Cr.
Gharrah Creek
Gharrah
Tatta
Meerpoor
Piniaree R.
RIVER INDUS
Wangee R.
Piti R.
Piti Mouth
Coondee or Kadi Mouth
R. Coondee
Rahu R.
Kai Mouth
R. Kai
Pitiani R.
Buggaur R.
Peer Putta
Meerpoor
Buggaur
Durajo
Coongra R.
Muggribee
Mull R.
Pitiani Mouth
Coomeesa R.
R. Jua or Seeshur
Guloo Branch
Seeran
R. Seeran
R. Gorabee
Dubba Mouth
Jua Mouth
Hujjamree Mouth
R. Bua
Richel
Gorabaree
Hujjamree R.
Sian Branch
Shah Bunder
Khetty
R. INDUS
Hujjamree Mouth
Kediwari Mouth
Mootnee R.
Mull R.
Jahn Mahomed
Kukiwari Mouth
Kaha Mouth
Mull Mouth
Waree Mouth
Seer R.
South West

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Edwd Weller

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Between the boundaries thus indicated, the plain of the Indus will be seen to vary much in width. Its physical aspect is characterised by a very remarkable uniformity throughout, in the entire absence of channels for natural drainage, in its almost uniform slope both towards the sea and away from the river's banks, and in its mineral character. I have shown that the slope of the valley in a direct line to the sea is about 9 inches in the mile, and the lateral slopes on either side of the river are in many cases quite as much. The river throughout this portion of its course passes along a ridge, and is many feet above the land a few miles distant on either side of it. This vast plain is entirely composed of the finest silicious deposit mixed with a variable proportion of argillaceous matter and mica; some portions resist the action of the river better than others, but generally the banks are easily cut into. Such is the fineness of the soil, that neither in the bed of the stream nor in any portion of the plains is it possible to find a grain of sand so large as a pin's head.

The Indus, like other tropical rivers, is subject to annual inundation, the extent of which has been carefully registered for many years both at Sukkur and at Kotree. At the former place it generally rises from 12 to 13 feet above a fixed datum, assumed as its low or cold-season level; but the fluctuations of the river at this latter period are considerable at this point, the water having in some seasons fallen to more than 2 feet below the datum. The inundation level is, however, more permanent at Kotree. On the contrary, the level of the water is more permanent during the low season, and the fluctuations are greater in the inundation. In ten years the water was only four times below zero, and it twice reached 18 feet on the gauge at the height of the inundation.

The rise between February or March and the middle of June may be attributed chiefly to the melting of snow in the Himalayas, while that from 15th June to September is the result of the monsoon rains discharged on the southern slopes of the same mountains.

The amount of rainfall in Sind is so small that cultivation may be said to be entirely dependent upon the rise of the river. The whole country is intersected by a network of canals by which water is, during the inundation season, led to great distances, and for which the lateral and seaward slopes of the land afford great facilities. These canals are generally opened in the month of May, when the land is prepared for the crops, and the supply ceases in September. An early fall in the river is, of course, most injurious to the crops, but generally the supply may be considered as quite as reliable as that

derived from rain in those portions of India in which agriculture is dependent upon that source of supply.

The maintenance of these canals in a state of efficiency is under the supervision of Government officers, and both the revenue of the State and the prosperity of the cultivators is, of course, dependent upon the due performance of the duty.

Government are at the expense of clearing all the main channels, and have abolished the system of forced labour which existed under the previous Native governments.*

The amount of silt contained in the water of the Indus is remarkably great. From a series of careful observations made at Sukkur and Kotree, it has been ascertained that, at the height of the inundation, the solid matter in the water amounted to about 43·6 parts in ten thousand by weight, and at the end of December to 17 parts. The discharge of the river at the former period is about 380,000 cubic feet per second, at the latter 680,000 cubic feet. Assuming a mean discharge of 200,000 cubic feet per second, and the amount of solid matter at 25 parts in ten thousand, we should have 5866 million cubic feet of material carried to sea in the year, or 217¼ million cubic yards, sufficient to cover 70 square miles with deposit one yard in thickness. I am not aware that any observations have been recorded which show so great a proportion of silt in any other river. The details of the experiments, with a description of the method of collecting the water from different depths, and the subsequent operations, are given in an appendix.

The river flows in a very shallow bed, and the banks are generally ill defined. During the low season navigation is difficult for boats drawing four feet, and the course of the stream becomes more tortuous as the inundation subsides. During the low season the channels wind about between the large sand-banks formed in the bed of the river, and are in process of continual change. The stream appears, by an automatic action and with almost life-like instinct, to adjust its surface slope with each change in the amount of water which passes down. At this season the falling in of the temporary banks is constantly taking place.

The banks of the inundation period, though much more stable than those above described, are by no means permanent, and some towns and villages have been swept away and rebuilt

* There are four modes of irrigation in Sind:—1st. By the Persian wheel, where the water is below the level of the land. 2nd. By natural flow, when the water in the canal is above the land. 3rd. By wells drawn by Persian wheels. 4th. By distributing water derived from rain from the natural drainage channels which issue from the hill ranges. Much land which has been flooded during the inundation is also brought under cultivation, and bears good crops without further irrigation, and there is also some cultivation in parts after rain.

on other sites two or three times within the last twenty years. These banks are frequently below the level of the river at the height of the inundation, and the crest of the inundation wave is then spilt over them, the water passing down the side slopes. Extensive tracts of country are then occasionally flooded, and a very large amount of water escapes from the river, especially in that part of the left bank below the junction of the Sutlej with the Indus, in the Bhawulpoor territory. Such floods, after passing into the low country bordering the desert, have often found their way into the Eastern Narra, and after filling innumerable dunds (natural depressions among the sand-hills), spread over the uncultivated plains as far south as Nowacote, or even into the Run of Cutch. In other seasons the flood has extended from the right bank about Kusmore, and having covered the whole country between Shikarpoor and Jacobabad has reached beyond Kyree Ghurree to the west.*

It will be seen from the distances to which these floods extend, that although it is merely the crest of the inundation wave which is spilt over the banks, the body of water thrown over the country must be very great. The floods frequently cause great damage, not only to existing cultivation, but to public buildings. As they take place only when the inundation is nearly at its height, the supply is cut off as soon as the crest of the wave has passed, and, as the water spread over the country is absorbed, the ground, unless injured by excessive and repeated floods, affords excellent spring crops, which reimburse the cultivator for the loss he may have sustained by the destruction of the usual inundation crop. A succession of such floods, however, is found not only to destroy the land, but to make the cultivator disinclined to undertake the labour of preparing his land for the safer and more legitimate husbandry of the autumn crop. It has not unfrequently happened that in the expectation of a flood which did not occur, land has been left uncultivated, and the opportunity for putting in a crop has been entirely lost.†

The extensive sand-banks formed in the bed of the river are frequently many feet above the level of the water during the low season, and become quickly covered by a thick growth of young tamarisk; those which are not swept away by the next inundation, being thus protected from the action of the current on their surface, are gradually raised by successive deposits

* When the crest of the inundation wave sets with force against one bank of the river, the height of the water pressing upon that bank is considerably greater than that upon the opposite bank, and this determines the direction taken by the flood.

† These extensive floods are confined to the upper portion of the province.

of silt to the level of the high banks, and frequently become comparatively permanent islands bearing forest trees. The main banks, where they have not been cleared for cultivation, are also covered with a luxuriant growth of tamarisk and elephant-grass, or forest trees.

The heavily charged water which passes through this vegetation is deprived of its silt, which tends to raise the level of the bank, and the velocity of the water which escapes from the river is checked.

I have stated that throughout the large area occupied by the Indus Valley, the nature of the surface soil may be said to be identical from Mittee to the sea, and that the river occupies a ridge having a tortuous course of 540 miles, in a direct distance of 330 miles between those points; and I would remark here, that had it taken, like an ordinary drainage channel, the lowest ground, its course would have been materially shortened, and it would have passed down the still existing channel, called the Rhain, into the Eastern Narra, and by Nowacote to the Run of Cutch. These old channels are still of very considerable size, and it is an interesting question whether they indicate the course of the river at any former period.

The country between the Narra and the present river contains many remains of old channels, some of which extend for many miles continuously, and have well defined banks, with a glacis on each side. They have in many cases a very tortuous course, but are straighter as they approach the sea. There are so many of these old channels to the eastward of the present course of the river, while such marks are rare and indistinct on the right bank, that one is led to the conclusion that the river has gradually worked to the westward. There is unfortunately no authentic map of the Eastern Delta, or of the country south of Meerpoor, which shows the course of the old channels now referred to, which terminate in the Run of Cutch. It is possible that formerly the chief outlets of the river may have been by these channels, and that the accumulation of an enormous deposit, derived from the river, in the Run, in conjunction with an upheaval of that district, which there are grounds to believe took place in the year 1819 (Burns' Travels), may have forced the river to form new channels having more direct communication with the ocean, and thus to assume its present course.*

* In Sir A. Burns' Travels into Bokhara, it is stated that previous to 1762 the Phooran, then a branch of the Indus, "emptied itself into the sea by passing the western shores of Cutch. Its annual inundations watered the soil," and afforded the means of irrigation. It is stated that the supply was not wholly cut off by an artificial embankment, but that in 1802 the Indus water was entirely excluded by

The completion of the survey of the Eastern Delta and the extension of the series of levels into the Run of Cutch will probably throw some light upon these subjects.*

It would, I think, be an assumption, for which there is no sufficient evidence, to state that the whole of this Indus plain has been regained from the sea by deposit from the river. The height of Mittee, 257 feet above mean sea-level, and the still greater height of places such as Mooltan and others further north, where the same general features are found, renders this more than improbable. But further it is to be observed that at Sukkur the river is crossed by a barrier of rock, the depth of water over which in the low season is only 5 or 6 feet. Between Kotree and Hyderabad, also, there can be little doubt that the rock on either side is connected at no great depth. At Jerruck rock appears on both sides of the river, and again on the line south from Tatta to Peerputta. There are thus indications that the actual depth of deposit at and near these points, at least, must be very slight; and it can hardly be supposed either that the sea ever extended far up the valley, or that the river can have gradually worked itself up its own glacis from a much

the erection of another bund at Ali Bunder. In June, 1819, an earthquake occurred which raised a mound which passed entirely across the course of the Phooran, separating it from connexion with its former outlet into the sea; but this, as well as the artificial embankments, are said to have been forced by the large flood of 1826, which came down from Bhawulpoor and along the Eastern Narra, and ultimately reached the Run of Cutch. The Phooran is a well defined and large channel, across which several bunds have been constructed in the lower part of its course to retain water which enters it from the canals which tail into it from the main river as well as the Foolalee; but such bunds could not have been constructed until after the Phooran had ceased to derive a supply by direct communication with the Indus. This direct communication had therefore probably ceased at the first period above referred to, or at all events before 1802.—*Burns*, vol. i. pp. 309-315.

* Sir A. Burns describes the Run as extending about 200 miles in length, and about 35 in breadth, or occupying an area of about 7000 square miles. The whole tract may truly be said to be a "terra hospitibus ferox;" fresh water is never to be had anywhere but on islands, and there it is scarce; it has no herbage, and vegetable life is only discernible in the shape of stunted tamarisk-bushes. It differs as widely from what is termed the sandy desert as it does from the cultivated plain. It has been denominated a marsh by geographers, which has given rise to many erroneous impressions regarding it. It has none of the characteristics of one; it is not covered or saturated with water but at certain periods; it has neither weeds nor grass in its bed, which, instead of being slimy, is hard, dry, and sandy, of such a consistency as never to become clayey unless from a long continuance of water on an individual spot, nor is it otherwise fenny or swampy. It is a vast expanse of flat, hardened sand, encrusted with salt sometimes an inch deep (the water having been evaporated by the sun). The natives of Cutch, Mahomedans as well as Hindoos, believe that the Run was formerly a sea: they point out at this day different positions said to have been harbours. The Run has communications with the sea both on the east and west by means of the Gulf of Cutch and a branch of the Indus, and it is flooded from both these openings as soon as the south-westerly winds set in about April each year; the greater portion of the Run is thus annually flooded.

lower level, and surmounted such a rock barrier as that at Sukkur, as must have been the case had its original course been much either to the east or the west of that point.

I believe that hitherto no adequate explanation has been given of the oscillation of rivers in their courses. Why, for instance, does the Indus in passing down an incline which may be considered perfectly regular between the two extreme points herein referred to, 330 miles apart, assume a course 540 miles long? I am aware that Mr. James Fergusson, in his 'Notes on Recent Changes in the Delta of the Ganges,' has suggested a theory the result of which, if I correctly understand his meaning, would be that the flatter the country through which a river passes, the sharper would be the curves. I believe this to be contrary to fact, and that the only explanation which can be given of the subject is that a river discharging itself down any continuous slope, in a soil capable of being acted upon by it, must assume such a course and section as may enable it to adjust its surface slope to every variation in its section or body of discharge at each season of the year. It is obvious that the channel of such a river as the Indus, passing through a country consisting of material so easily acted upon as that upon its banks, could have no permanence if its course were materially shorter and its surface slope greater than that it has assumed.

I would also point to the fact that, during the inundation when carrying a large body of water, the course of the Indus is more direct than in its low state, when the water not only follows the course of the larger reaches of the river, but winds from side to side, or round the extensive sand-banks within its wide channels, thus adapting its surface slope to suit the small and ever-varying amount of discharge at that season. Should my views on this subject be correct, it would result that the larger the body of water and the less the surface slope of the country, the more direct will be the course of a river; and, on the contrary, the sharpness of the bends of a large river passing down a plain would indicate the existence of a considerable slope in the country. I should, in this manner, infer that the valley of the Tigris between Bagdad and the marshes north of Kornah has a more considerable slope than that of the Indus. The general statement I venture to make is, that with a fixed or virtually fixed maximum discharge and an ascertained difference of level between any two points on a large river passing through an alluvial plain, the length of its course is also absolutely fixed. The longer, therefore, a river becomes by extending its delta to seaward, the greater tendency will there be to assume a more direct course.

I have stated that the boundary of the valley of the Indus on

the eastern side is the Thurr or Desert, and it is desirable that I should describe it.

In mineral character portions of this district differ very little from the great plain of the Indus: other portions consist of pure siliceous white sand, but the district has everywhere been raised into ridges and low hills, which are very remarkable as having a north-east strike over a very large area. The valleys or depressions between the hills have frequently no outlet or communication with each other, and are at a very low level. Where wells have been dug in these basins, water is found only at great depths. The height of these hills increases towards the south, and there are more distinct indications of the existence of a soft and very friable sandstone formation below the surface. The remarkable similarity of the surface of a large extent of this desert with that of the Indus plain would indicate that the formations are identical, the desert portion having been subject to upheaval by a force acting in north-east and south-west lines; hitherto no levels have been extended into this district.

Whatever may have been the position of the Delta of the Indus in former times, and there are grounds for supposing that it has been considerably more to the eastward, it must now be deemed to commence at some distance to the south of Tatta. It will be seen that only two branches leave the river from the right bank, the Buggaur and Hujjamree. The first, now a small channel, not more than 80 yards in width during the inundation, discharges its water after a very winding course into what must be considered as a large lagoon extending from the vicinity of Kurrachee to the main embouchure of the river; the second, the Hujjamree, carries off a large body of water, about one-third of that in the main stream. It passes by a winding course to the sea, and its mouth affords the best navigable entrance for trading-vessels; it is indeed the only entrance now used; and the town of Khetty, situated on it, was the chief port of Sind for the trade with Bombay, and generally for all trade carried on by native coasting-vessels, until the construction of the railway, joined with the high prices, the result of the American war, enabled the merchant to divert the traffic in cotton, wool, and such other articles as would bear the extra charge of transport, to Kurrachee.

There are also only two delta channels which leave the Indus from its west bank—the Mootnee and the Mull; both of these diverge from the river below the point at which the Hujjamree takes off. The left bank delta has not yet been properly surveyed, and very little is known of this district even by the revenue officers.

The western delta has very recently been surveyed by Captain Macdonald. The coast will be seen, by the map, to extend in nearly a straight line from the mouth of the Hujjamree to the entrance of the Kurrachee harbour, and is formed by a line of sand-bank topped by low dunes.

The coast is extremely flat, and the extent of shore left dry at low tide very considerable.* Behind the screen formed by the coast-line, there is a very large area of marsh-land permeated in every direction by tortuous creeks and channels, the tidal water to supply which is derived from a number of wide but shallow passages or openings in the coast-line. These openings have been most improperly called mouths of the Indus; but it is obvious that they are in fact merely passages for the tidal water to and from the lagoon. From their connexion with each other, by means of the large creeks within, a safe navigable canal is afforded during the monsoon season to the steamers which ply on the Indus between Ghizree, close to Kurrachee, and the river, when such vessels are quite unfit to make the direct passage from Kurrachee to the river-mouth. Within the lagoon the channels are well defined, though very tortuous, and deepen gradually as the distance from the Indus increases. The soundings in those to the northward are as much as 3, 4, and $4\frac{1}{2}$ fathoms at low water, at many miles from the sea. The mud-banks within this lagoon have now been raised nearly to the level of ordinary high-water mark, by deposit of salt mud on which mangrove and soda-plants are the only vegetation. This mud is blue-black in colour and very fine; but, when dried, it becomes of the same light-drab colour as the Indus mud.

The bay and harbour of Kurrachee is situated at the extreme northern end of this delta. The bay is formed by Munora point, a natural hill, consisting of clay beds capped by conglomerate, at the southern extremity of a reef about 10 miles in length, by which it is united to the mainland, and on which the action of the surf, which breaks directly upon it, has formed a beach, capped by a narrow ridge of blown sand. The opening of the bay between Munora and Clifton is about $3\frac{1}{2}$ miles wide, but this opening is blocked by rocky islands in the centre, and by the island of Keamaree at some distance in the rear. The entrance to the harbour, and the only navigable channel, is close to Munora, the anchorage extending from within the shelter of that point to the western end of Keamaree. With the exception of this comparatively deep portion, and two branch channels of no great extent, the whole space within presents at low water

* The map shows the line of high water only.

an area of extensive mud-flats, some of which are covered by mangrove-bushes. The tidal area is generally at a level of 6 or 8 feet above low water, or from 1 to 3 feet below high water at spring tides. The surface consists of a layer from 3 to 6 feet thick of stiff, black mud, formed of silt mixed with decayed vegetable matter, lying on a bed of sand of variable quality, in some places fine and very thick—a quicksand, in fact—in others coarser, containing sea-shells or approaching gravel. The whole overlies a bed of stiff blue clay, which appears to be the natural surface. The superficial deposits extend to from 9 to 25 feet *below* low-water mark.

On a careful examination of these superficial deposits, it has been found that the stiff black mud, mixed with vegetable matter, is identical with that found on the mud-banks within the lagoon, which has been already described. Its mineral character, as well as that of the fine sands below it, and the whole of the surface of Keamaree, is marked by the presence of a very fine white quartz, mixed with a large proportion of mica, and is thus identical in composition with the silt carried to sea in the waters of the Indus.

The presence of mica within Kurrachee Harbour must be regarded as affording a strong presumption that the deposit within its area is derived from the Indus. I have examined the sands in the minor drainage channels, which discharge into the sea between the mouth of that river and Sonmeanee, and from several places on the Mekran coast, and found them all characterised by the entire absence of this mineral. It does not exist on the Mekran coast, where the set of the current is to the eastward, and I can see no escape from the conclusion that it is swept up the coast from the mouths of the Indus.

The agency by which this is effected will be easily understood by referring to the map of the coast-line.

The south-west monsoon breaks upon this coast early in May, and lasts without cessation until September, during the whole of which period a heavy surf beats upon the shore. It is precisely during this period that the Indus is discharging its flood-waters so heavily charged with sand and silt. The direction in which the surf breaks upon the coast is marked upon the map by a series of parallel broken lines, which form a considerable angle with the general coast-line. The result of this oblique action of the sea-stroke, even upon coasts which are not subject to winds which prevail continuously for any long period, is not only to force any matters held in suspension in the water in the direction of the stroke, but, as shown by Sir H. De la Beche in the extracts appended, to produce a shore current.

"Though, for convenience, the Mediterranean has been treated as a tideless sea, and without motion, this is not strictly correct, inasmuch as small tides are felt in it, and currents are found. Indeed, as respects the latter, when powerful winds by their friction force the surface waters in some given direction for the time, well seen where driven against any part of the boundary coasts,* the movement is then sufficient to carry any substances, mechanically suspended, to distances proportionate to the power and continuance of the winds."—P. 82.

For many miles to seaward the depths of the Indus coast are within 8 fathoms, and the 4-fathom line extends from Munora Head in almost a strait line nearly parallel to the coast.

"The observer has now to consider the distribution of fine matter in mechanical suspension by means of ocean currents. Some of these are known to be very constant in their courses, others periodical, and many temporary. We have seen that the pressure of strong and long-continued winds forces up water by their friction on its surface in tideless seas, and consequently would expect that in the open ocean similar winds would force water before them, though the absence of land would produce a modification in the result. When the area so acted upon was bounded by a single range of coast, the modification would be less; and when two lines of coast presented themselves between which the water could be forced and lateral fall prevented, there would be an approximation to the effects observable at the north and south extremities of the Caspian, or on the east and west shores of the Black Seas, where the waters are pressed forward by the needful winds."—Pp. 106, 107.

"With respect to temporary currents, they are found to be innumerable; severe gales of wind of long duration readily force the surface water before them. Among channels and along coasts these are chiefly felt: the two boundary shores or the single coast opposing the further rise of water and throwing them off in the manner of tidal waves."—P. 110.

"When detrital matter is thrown into the tides it is borne to and fro by them according to their flow and ebb; and the observer will have abundant opportunities of seeing on the coasts of the British Islands and on the ocean shores of Europe, that the river waters when swollen by rains bear outwards with the ebb, and in the direction it takes along shore much mechanically suspended detritus, which does not again enter the rivers unless under very favourable circumstances. As a whole, much fine detritus thus derived is carried coastwise by the ebb, and accumulations are formed of it if there be sufficient continued repose in that direction; so that, should a sheltering headland run out and a bay be formed between it and the embouchure of the river, there is a tendency to deposit the finer sediment in the locality so sheltered."—P. 100.

The manner in which beach material is swept along a coast in the direction of the sea-stroke is well illustrated in figs.

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* An observer may often have opportunities in the ports of the Mediterranean of seeing the rise or depression (as the case may be) of the sea, according as the winds at the time may be blowing with strength off or on shore. Canals frequently afford good opportunities of observing this kind of action of wind on water, for the canal levels in still weather being accurately known, it becomes easy to see how much these waters are raised or depressed as the winds may press them in one direction or another. Mr. Smeaton found that in a canal four miles in length, the water was kept up four inches higher at one end than at the other by the action of the wind along the canal. The Caspian Sea is several feet higher at either end, according as a strong northerly or southerly wind may prevail.

53 and 54, pp. 66 and 67, of the same book. It is obvious that in fig. 54 (Fig. 1, *below*), not only has the beach, *b b*, travelled from *g*, and been spread along the whole intermediate space between *g* and *c*, but whenever the winds blow for any length of time in the direction marked by the arrows, there must be a continuous movement of materials in the same direction; and should there be a bay beyond *c*, in which the material can find shelter and repose there, accumulation must take place.

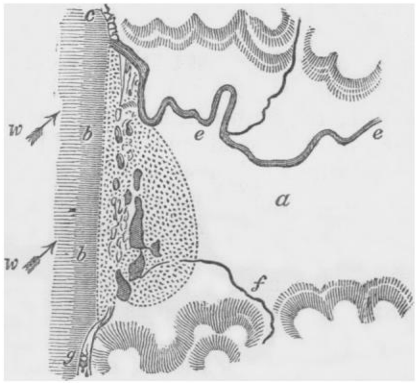


Fig. 1.

The manner in which the deposit in the lagoon, and within Kurrachee harbour has been formed, is extremely well described in the last of the above extracts from Sir Henry De la Beche, and it would appear that the whole shore-line between the mouths of the Indus and Munora has been formed by the action of the sea-stroke forcing the sand and silt discharged by the river in the direction of Kurrachee Harbour.*

In July, 1865, a steamer was sent down the river to the mouth of the Kujamree, and anchored within the bar, but as far out as she could lie with safety. 860 pint bottles corked, wired, and weighed to float as low as possible, were thrown overboard at intervals between 8 A.M. and 5.10 P.M. on the 27th July; 61 of these were found on the beach of Clifton, close to Kurrachee, by 1.31 P.M. on the 29th, but these were ascertained to have been 47 hours in transit; and the direct distance being 49 miles, it may, perhaps, be assumed that the assistance of a current in this direction, amounting to 1 mile an hour, was thus proved.

By the 4th August 214 bottles had been picked up, either on Clifton Beach or within Ghizree Creek. With so strong an indraft into the numerous openings to the Lagoon as must

* Large quantities of driftwood, consisting of branches of trees known to grow on the banks of the Indus, are cast on shore at Clifton and Keamaree, and carried into the harbour during each monsoon. The coast is so shallow, and the surf beating upon it is so heavy during the monsoon, that no vessel can approach it from seaward, and it is therefore difficult to test the existence of a coast current by actual experiment.

exist along the whole of this line of coast, a great many of the bottles were doubtless prevented from reaching so far to the north, and the above number, which were found, may be deemed as large a proportion as could be expected; but in addition to the indraft, the bottles floating at the surface were exposed on approaching the coast to the force of the surge, and would necessarily partake in the motion of the breaking crests, and be driven leeward; they are not, therefore, a fair indication of the course taken by the sand and silt held in suspension, and diffused through the whole body of the water.

In this manner the circumstance that none of the bottles were found either within Kurrachee Harbour or on Keamaree may be explained.

From the action of the coast current, whose existence may now perhaps be assumed as proved, there must be a considerable banking-up of water during the monsoon within Kurrachee Harbour. I have called attention already to the position of the Island of Keamarree, and have stated that it is composed entirely of fine sand; the portion above high-water mark consists entirely of blown sand derïved from its own shore. At many feet below low-water mark its composition appears to be the same, and the whole must, I believe, be regarded as a deposit from the sea, due to the banked-up water in the harbour deflecting the coast current, and throwing it off towards Munora Head in the manner I have endeavoured to exemplify by the arrows in the appended sketch. Should this view be adopted as correct, the existence of the island in its present form and position may be considered as a further illustration of the existence of the coast current.

I have stated that both in the Lagoon and in Kurrachee Harbour the superficial black mud is mixed with a large quantity of decayed vegetable matter. A large quantity of a very dark brown vegetable fibre, in a fine state, is deposited each monsoon in any sheltered spots, such as on either side of a stone groin which has been carried out from Keamaree towards Munora; this, when first deposited, is so soft that a man walking on it sinks to his knees. On examining specimens of this material, and of the more solid matter from within the harbour, Dr. Robert Haines, chemical analyser at Bombay, wrote :—" What I think may be taken as quite certain is that the vegetable matter is not the remains of any phanerogamous plant, the structure is entirely cellular, even the bundles of apparent fibres in the larger masses are mere aggregations of elongated cells."

The first specimen sent had been washed and dried; subse-

quently a mass of wet mud, 3 inches cube, was sent in a tin box. Dr. Haine's report on it was thus given :—

"It confirms for the most part my first opinion, except that the fragment, which in the dried state of the first specimen I took for minute fronds of smaller sea-weeds, are now seen to be the loosely aggregated fibres which make up the so-called stem of a larger sea-weed. The bundles of fibrous matter, where they have not been disturbed, are held together by a brown membranous tube, a sort of skin, comprised of very regular elongated cells bevilling into each other at the ends. The fibres are flat and very thin, composed of cellular tissue. This is exactly the structure of a sea-weed stem, the still looser half mucillaginous, intermediary cells having rotted and dissolved away and left the tissues separate. I found one small fragment of an exogenous branch embedded in the mass. I have not a doubt of the whole being a marine littoral deposit. The fragmentary state of the vegetable matter forbids the supposition of its having grown *in situ;* it appears to have been deposited with the mud in its present broken state."

From the above description it is evident that the large deposit of black mud, mixed with sea-weed and mica, has been swept into Kurrachee Harbour and into the Lagoon by the tides, and by the current which sweeps up the coast at the very time when, owing to the heavy surf breaking upon the coast, a vast quantity of sea-weed must be broken up and swept away.

The lift of the tides on this coast varies from 8 to 11 feet at springs; their course is in a direction parallel to the coast-line, the flood-tide coming from the north-west and the ebb running in the opposite direction. During the monsoon months there is a strong set in the offing to the south-east, or in a direction contrary to that along the shore of the Lagoon, which is entirely local. Both currents are produced by the same cause, the action of the long-continued sea-stroke on a coast-line forming a considerable angle with the crests of the monsoon waves. (See Map, on which the probable course of the two currents is indicated by arrows.) By the action of the current in the offing it is probable that much silt, which has been swept to the northward as far as Kurrachee Harbour, may be again carried to the southward, and be perhaps eventually deposited in the eastern delta channels or carried into the Run of Cutch.*

The action which I have endeavoured to trace must have a considerable influence in checking the growth of the delta to seaward, the surface of each successive monsoon exerting its immense power in the removal of any deposit which would otherwise tend to extend the banks by which the main channels

* See note, p. 73. It seems highly probable that the enormous deposit in the Run may have been derived from the Indus.

discharge into the ocean. The progress to seaward is thus dependent upon the advance of the whole coast-line between the mouths of the river and Ghizree, a process which must be extremely slow.

In Mr. Fergusson's 'Memoir on the Delta of the Ganges,' a remarkable depression in the bed of the sea, called "the Swatch," is noticed, and its existence is attributed to the meeting of tidal waves proceeding from opposite directions. A depression very similar in character exists off the mouths of the Indus, and called by the same name on the Charts. In this case it cannot be caused by any action of the tides; it is merely a natural gorge or narrow valley extending between two banks, and communicating directly at its southern extremity with the deep ocean. The two banks are themselves on different levels—that to the eastward having 14 to 16 fathoms, while the western bank has 45 to 50 fathoms. The soundings within "the Swatch" are irregular, varying from 100 fathoms to 160 and 200 fathoms, with no bottom. The line upon the Chart, intended to show the limit of 100 fathoms, may be considered as marking the crest of a submerged plain, beyond which there is a rapid increase in depth. This crest appears to maintain a course nearly parallel to the general coast-line along the whole of the Mekran coast.

APPENDIX.

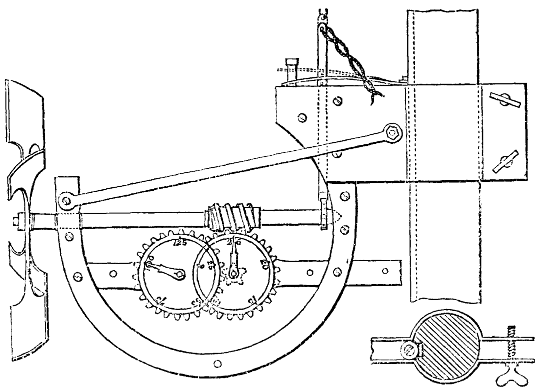
Description of the Mode adopted in taking Observations to determine the velocity of the Indus, and the amount of solid matter in its Water, at different depths.

Fig. 1 represents the instrument used for taking the velocities, which was a modification of Woltman's Mill. It was fitted to a round pole, or piece

FIG. 1.

INSTRUMENT FOR MEASURING THE VELOCITY OF THE CURRENT IN THE RIVER INDUS AND CANALS IN SIND.

Reduced to one-fourth the size.



of iron gas-pipe about 16 feet long, having an iron cross-head fixed to the top to show the axis of the instrument, which could thus be made to correspond with the direction of the surface-current. The correctness of the instrument had been previously ascertained by trials; the number of revolutions made by the vanes in a measured distance when dragged through still water, at various velocities, was found in each case to correspond.

The observations were taken from a boat, either fastened to the bank or anchored in the stream. The instrument was clamped to the rod at the required depth. As soon as the pole was in an upright position, with the cross-head in the proper direction, the trigger was pulled. The vane was usually allowed to revolve for 30 seconds, when the trigger was dropped, and the result registered by the index recorded. The observations were in every case repeated; no single observation was relied on; and whenever there was any material difference between two experiments, the observations were continued.

In very strong currents, and at any considerable depth below the surface, the instrument gave readings which varied considerably from each other: this was owing to the difficulty of holding the rod in the direct line of the current,

and to its vibration; but even in such case it was not difficult to obtain reliable results, as may be illustrated by the following observations:—

No. of Observations.	Revolutions.	No. of Observations.	Revolutions.
1	183½	5	194
2	226	6	204
3	233	7	233
4	225		

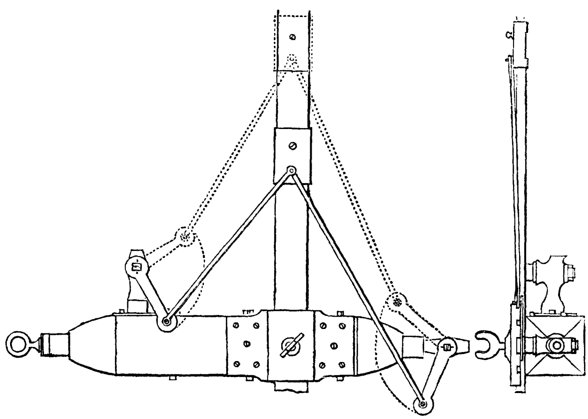
It may, perhaps, be taken for granted that the 2nd, 3rd, 4th, and 7th are nearly correct, and that the instrument was not held quite in the direction of the current in the other experiments. The mean of the above four gives 229 revolutions, equivalent to 9¼ feet per second, or very nearly 6½ miles an hour.

In every case the observations for velocity were taken first, and then the samples of water were drawn from corresponding depths. The apparatus employed to effect this is shown in Fig. 2. The iron rod on which the bottle

FIG. 2.

BOTTLE FOR TAKING WATER FROM BELOW THE SURFACE, TO ASCERTAIN THE QUANTITY OF SILT.

Reduced to one-eighth the size.



could be fixed at any required height above the foot was 14 or 16 feet in length. The valves or cocks were worked by strings fastened to the brass slide, and passed over pulleys at both ends of the rod. The water so drawn was at once put into bottles, arranged in order in a box made for the purpose, and the whole then carefully filtered. The filters, previous to use, were adjusted in the usual manner, and with the deposit, were thoroughly dried on a sand bath, and weighed in opposite scales. The quantity of water was accurately measured in the usual graduated glass measures, and the specific gravities were obtained by means of the specific gravity bottle.

An examination of the recorded velocities at different depths will show that some confidence may be felt in the correctness of the observations with the

instrument employed. With respect to the variation in the proportion of silt at different depths, the facts prove that the material in suspension is not distributed in any exact proportion to the depths and velocities. Taken as a whole, however, the results show but few of these anomalies. In the Sukkur observations, the proportion of salt increases with the depth with considerable regularity, though here also a few exceptions occur.

The mean result of the observations at Kotree, in November, is that the quantity of silt amounts to 1-672nd part of the water by weight; but as no observations could be taken where the river was deepest and most rapid, this fraction is too small to represent the proportion in the whole discharge of the river. The observations taken at Sukkur, in December, give the proportion 1-516; but this again, owing to the access of flood-water during the experiments, gives too large a value, and I am disposed to adopt as an approximation 1-550 or 1-600, say 16·6 parts in ten thousand as the proportion of silt by weight in the whole discharge of the river during the low season, or somewhat less than half that contained in it during the height of the inundation, viz., 43·6 parts in ten thousand.

It may be observed that the actual quantity of sand and silt moving forward with the current at any one time must be the same in each section of the river. The rule which is applicable to the uniform discharge of water in different river sections must apply equally to the solid material held in suspension. Where the velocity is exceptional, as in the narrow pass at Sukkur, the water and sand are more intimately mixed, and the surface-water will contain a larger proportion of sedimentary matter than elsewhere; but the total quantity of solid matter is no more affected by the additional velocity than is the volume of water discharged by the river.

RECORD of OBSERVATIONS to ascertain the amount of SILT contained in the Water of the INDUS during both the Inundation and the Low Seasons, made in the months of July, August, November, and December, 1864.

Date.	Site.	Gauge.		Depth of Water.		Depth from Surface.		Velocity per Second.	Quantity of Water.			Deposit on Filter.	Proportion of Silt to Water.	Specific Gravity of Silt.
1864.		′	″	′	″	′	″		lbs.	ozs.	dwts.	Grains.		
July 23 ..	Sukkur	10	11	10	0	6	10	9·5	2	2	5	62	1/244	
									1	1	1½	36	1/208	
									0	14	0	26	1/235	
									4	1	6½	124	1/232	
,, 25 ..	Ditto	11	4	8	6	6	10	3·5	2	0	0	50	1/280	
									1	13	0	51	1/248	
									1	15	0	47	1/288	
									5	12	0	148	1/272	
,, 27 ..	Ditto	11	8½	8	9	3	9	4·58	2	4	2	72	1/220	
									2	2	6	75	1/202	
									1	13	4	63	1/204	
									6	4	4	210	1/209	
,, 28 ..	Ditto	11	11	9	2	6	2	4·2	2	2	3¾	64	1/235	
									1	12	1½	51	1/241	
									2	3	3	85	1/182	
									1	12	2	70	1/176	
									7	14	2¼	270	1/204	

,, 29 ..	Ditto	11	11	12	0	10	0	3·1	1	14	0	57	1/230	
									1	9	6	73	1/154	
									2	4	0	70	1/225	
									2	4	4	78	1/204	
									8	0	2	278	1/202	
August 1 ..	Ditto	12	2	8	6	6	6	2·6	2	3	3	62	1/249	
						4	6	3·2	2	3	3	59	1/262	
						2	6	4·0	2	2	6⅓	47	1/317	
						1	0	4·2	2	3	3	50	1/309	
									8	12	1⅓	218	1/281	
,, 3 ..	Ditto	12	3½	9	6	7	6	3·8	2	3	0	62	1/247	
						5	6	4·1	2	0	0	65	1/205	
						3	6	4·6	1	12	3	49	1/253	
						1	6	3·5	1	8	0	39	1/269	
						0	6	3·9		..		..	..	
									7	7	3	215	1/242	
,, 9 ..	Ditto	13	0	8	6	6	6	3·6	1	13	2¾	47	1/272	
						4	6	4·1	2	0	5	50	1/288	
						2	6	5·2	1	4	4½	26	1/346	
						0	6	5·4	2	1	0	48	1/300	
									7	3	4¼	171	1/295	2464

RECORD of OBSERVATIONS to ascertain the amount of SILT contained in the Water of the INDUS, &c.—*continued.*

Date.	Site.	Gauge.		Depth of Water.		Depth from Surface.		Velocity per Second.	Quantity of Water.			Deposit on Filter.	Proportion of Silt to Water.	Specific Gravity of Silt.	
1864.		′	″	′	″	′	″		lbs.	ozs.	dwts.	Grains.			
August 3 ..	Sukkur	12	$3\frac{1}{2}$	11	0	8	6	About 4·0	13	3	0	449	1/205	2688	
,, 9 ..	Ditto	13	0	11	0	10	0	..	13	12	$4\frac{1}{2}$	455	1/212		
									26	15	$4\frac{1}{2}$	904	1/208		
July 28 ..	Centre of river	11	11	50 to 90 ft.		11	9	Not observed	2	4	0	75	1/210		
				Total at Sukkur ..				.. .. ..	84	11	$3\frac{5}{6}$	2613	1/227	..	Mean for Inundation period.
December 24	Sukkur	0	7	7	6	5	6	1·75	2	14	$3\frac{1}{2}$	38	1/534		
						3	6	1·95	2	13	$1\frac{1}{2}$	20	1/988		
						1	6	2·66	2	15	0	20	1/1028		
								2·08							
									8	10	5	78	1/777		
,, 26	Ditto	1	1	7	3	5	3	4·27	2	11	$4\frac{3}{4}$	22	1/821		
						3	3	4·57	2	3	0	20	1/765		
						1	3	5·03	2	15	$2\frac{1}{2}$	23	1/809		
						Surface		5·03	2	3	$2\frac{1}{2}$	16	1/965		
									10	1	$1\frac{3}{4}$	81	1/870		

,,	27	Ditto	1	8	9	8	7	8	4·86	2	2	5	38	1/398
							5	8	5·5	2	3	2	36	1/428
							3	8	6·26	2	6	0	33	1/503
							1	8	6·47	2	3	0	35	1/437
										8	14	7	142	1/440
,,	28	Ditto	2	0	9	0	7	0	5·16	2	5	6	90	1/183
							5	0	5·5	2	5	6½	60	1/275
							3	0	6·72	2	6	0	45	1/369
							1	0	6·93	2	6	0	44	1/378
										9	7	4½	239	1/277
	29	Ditto	1	11	7	4	5	4	5·54	2	3	4¾	36	1/432
							3	4	6·21	2	5	7	36	1/460
							1	4	6·80		..		..	..
							0	4	6·80	3	3	3	39	1/576
										7	12	6¾	111	1/492
,,	30	Ditto	1	7	8	5	6	5	4·07	2	6	0	35	1/475
							4	5	4·74	2	6	0	33	1/503
							2	5	4·87	2	5	6	30½	1/541
							0	5	5·12	2	3	3	21	1/737
										9	5	1	119½	1/546

RECORD of OBSERVATIONS to ascertain the amount of SILT contained in the Water of the INDUS, &c.—*continued.*

Date.	Site.	Gauge.	Depth of Water.	Depth from Surface.	Velocity per Second.	Quantity of Water. lbs.	ozs.	dwts.	Deposit on Filter.	Proportion of Silt to Water.	Specific Gravity of Silt.	
1864.		′ ″	′ ″	′ ″					Grains.			
December 31	Sukkur	1 4	7 3	5 3	4·03	2	0	0	26	1/537		
				3 3	4·62	1	5	2	28	1/332		
				1 3	5·16	1	8	6	17	1/637		
				0 3	5·29	2	2	0	20	1/743		
						7	0	0	91	1/538		
1865.												
January 2..	Ditto	0 10	2 6	0 6	2·66	2	2	6	20	1/760		
			2 11	0 11	4·04	3	0	0	29	1/724		
				Surface	·19	2	3	5	21	1/742		
						7	6	3	70	1/739		
			Total at Sukkur		.. .. ..	68	10	5	931½	1/516	..	= ·00148 mean for Low Season.
1864.												
November 23	Kotree	3 2	13 0	11 0	1·68	3	1	5	27	1/804		
				9 0	2·16	3	0	4	29	1/734		
				7 0	2·37	3	0	1½	26	1/810		
				5 0	2·62		..		..	..		
				4 0	..	3	1	6	32	1/895		
				3 0	2·68		..		..	..		
				1 0	2·73		..		..	..		
						12	4	0½	114	1/768		

,,	24	Ditto	3	0½	14	0	12	0	1·85	3	0	3	25	1/846		
							8	0	2·52	3	0	5	46	1/462		
							4	0	3·06	3	1	7½	34	1/642		
							Surface		3·48	3	2	3	28	1/787		
										12	5	2½	133	1/654		
,,	25	Ditto	3	0	14	0	12	0	..	2	13	2	37	1/535		
							8	0	..	3	1	0	30	1/714		
							4	0	..	3	3	1½	33	1/678		
							Surface		4·7	2	1	6	20	1/738		
										11	3	1½	120	1/653		
,,	26	Ditto	2	11	16	0	14	0	1·38	3	0	0	24	1/875		
							10	0	1·85	3	1	5	27	1/804		
							6	0	2·22	3	1	4½	28	1/774		
							2	0	2·22	2	15	0	25	1/822		
							Surface		2·56		..		..	..		
										12	2	1½	104	1/817		
,,	28	Ditto	2	10½	15	0	13	0	Variable	2	15	0	45	1/457		
							9	0		3	0	4⅓	40	1/530		
							5	0		3	1	4¼	44	1/492		
							2	0		2	15	4	24	1/866		
										12	0	4½	153	1/550		
					Total at Kotree					59	15	2½	624	1/672	..	= ·00149 mean for Low Season.